First Midterm Examination, CH20B, Winter 2018

Thursday, 1 February, 7:00 – 8:50 pm

10 am 11 am

en problems. Do all parts of all the problems. You
mplete the exam. You may use your textbook, three
d a noncommunicating calculator of your choice in
gible for any possible regrade, you must work

Problem 1:	20	of 20 points
Problem 2:	8	of 10 points
Problem 3:	15	of 15 points
Problem 4:	15	of 15 points
Problem 5:	15	of 15 points
Problem 6:	15	of 15 points
Problem 7:	10	of 10 points

$R = 8.314$ J/mol-K $= 0.08314$ L-bar/mol-K $= 0.08206$ L-atm/mol-K

Avogadro's number $= 6.022 \times 10^{23}$ mol^{-1}

3 SF

1. (20 points) A mixture of $Ca(ClO_3)_2(s)$ (molar mass = 206.98 g/mol) ~~and~~ $Ca(ClO)_2(s)$ (molar mass = 142.98 g/mol) ~~having~~ a total mass of 20.0 g is heated to 705°C in a container having a volume of 12.0 L. At this temperature both compounds completely decompose to produce $CaCl_2(s)$ and $O_2(g)$. After decomposition the pressure in the container is measured to be 1.633 atm. Calculate the mass of each of the two compounds in the original mixture. ~~You may~~ assume that the gas behaves ideally.

$Ca(ClO_3)_{2(s)} + Ca(ClO)_{2(s)} \longrightarrow 2CaCl_{2(s)} + 4O_{2(g)}$

6O + 2O = 8O
2Cl + 2Cl = 4Cl
2Ca

$P = 1.633$ atm
$V = 12$ L
$T = 705°C = 978.15$ K

x = mass of $Ca(ClO_3)_2$
y = mass of $Ca(ClO)_2$

$x + y = 20$
$x = 20 - y$

$PV = nRT$

$(1.633\ \cancel{atm})(12.0\ \cancel{L}) = n\left(0.08206\ \frac{\cancel{L\,atm}}{mol\,K}\right)(978.15\ \cancel{K})$

$19.596 = \left(80.266989\ \frac{}{mol}\right) n$

$n = 0.2441352322$ mol O_2
$= 0.4882704645$ mol oxygen

\# mol oxygen = 6(mol $Ca(ClO_3)_2$) + 2(mol $Ca(ClO)_2$)

\# mol $Ca(ClO_3)_2$ = $\dfrac{x}{206.98\ g/mol}$

\# mol $Ca(ClO)_2$ = $\dfrac{y}{142.98\ g/mol}$

\# mol oxygen = 0.4882704645 mol = $\dfrac{6x}{206.98\ g/mol} + \dfrac{2y}{142.98\ g/mol}$

$= \dfrac{6(20-y)}{206.98\ g/mol} + \dfrac{2y}{142.98\ g/mol}$

$14449.87632\ g = 17157.6 - 857.88y + 413.96$

$-2707.72368 = -443.92y$

$6.099575779\ g = y$

$x = 20 - y = 13.90042422\ g$

$\boxed{\begin{array}{l} 6.10\ g\ Ca(ClO)_2 \\ 13.9\ g\ Ca(ClO_3)_2 \end{array}}$

8

2. In interstellar space the number of atoms per liter is about 10^4 and the temperature is 100 K. Assume that these atoms are all H atoms (molar mass = 1.0078 g/mol.)

(a) (5 points) Determine the pressure of the gas in interstellar space in units of bar

(b) (5 points) Determine the average speed of the interstellar atoms.

a) $\frac{10^4 \text{ H atoms}}{\text{Liter}} \cdot \frac{\text{mol H}}{6.022\times10^{23} \text{ atoms H}} = \frac{1.66057788 \text{ E-20 mol H}}{\text{Liter}}$

$T = 100$ K

let $V = 1$

$PV = nRT$

$P = \frac{nRT}{V}$

$= \left(\frac{n}{V}\right)RT$ ✓ $= \left(\frac{1.66057788 \text{ E-20 mol H}}{\text{Liter}}\right)\left(\frac{0.08206 \text{ L atm}}{\text{mol K}}\right)(100 \text{ K})$

+5

$= 1.36267021 \text{ E-19 atm} \times \frac{101325 \text{ Pa}}{1 \text{ atm}} \times \frac{1 \text{ bar}}{10^5 \text{ Pa}}$

$= 1.38072559 \text{ E-19 bar}$

~~= 1.38 bar (with one sig fig P=1 bar)~~

$= \boxed{1.38\times10^{-19} \text{ bar}}$ ✓ (with 1 sig fig, $P = 1\times10^{-19}$ bar)

b) average speed $= \sqrt{\frac{8 k_B T}{m}}$ ~~$= \sqrt{\left(\frac{8(1.38065\times10^{-23} \text{ J K}^{-1})(100 \text{ K})}{1.67353039 \text{ E-23 kg}}\right)}$~~

~~1.66057788 E-20 mol · 2g · mol / 1.0078g~~

~~E 1.64777562 E-20~~

$1.66057788 \text{ E-20 mol} \cdot \frac{1.0078 \text{ g}}{\text{mol}}$

$= 1.67353039 \text{ E-20 g}$

~~= 1.67353039 E-23 kg~~

~~$= \sqrt{659.9939803 \frac{m^2}{s^2}}$~~

~~= 25.69 m/s~~

~~(with 1 sig fig = 30 m/s)~~

see back side

$\boxed{2569 \text{ m/s}}$

2.b) average speed:

$$\cancel{\bar{v} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8(8.314\ J\ K^{-1})(100\ K)}{1.0078\frac{g}{mol}(1.66057788E-24\ mol)(\frac{1\ kg}{1000\ g})}}}$$

$$\cancel{M \text{ in kg} = \frac{1.0078\ g}{1\ mol\ H}(1.66057788E-20\ mol\ H)}$$

~~1.66057788 E~~

$$\cancel{M \text{ in kg} = \frac{1.0078\ g}{1\ mol\ H} \cdot \frac{1\ mol\ H}{6.022\times10^{23}\ H\ atoms} \cdot \frac{1\ kg}{1000\ g}}$$

$$\cancel{= 1.0078\ g}$$

$$\cancel{= 1.67353039\ E-27\ kg / H\ atom}$$

$$\cancel{= 1.67353039\ E-24\ \frac{kg}{mo}}$$

2.b) $$M \text{ in kg} = \frac{1.0078\ g}{mol} \cdot \frac{1\ kg}{1000\ g}$$

$$= 0.0010078\ \frac{kg}{mol}$$

$$\bar{v} = \sqrt{\frac{8RT}{M\pi}} = \sqrt{\frac{8(8.314)(100)}{0.0010078}}$$

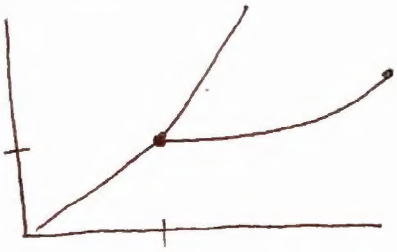
+3

$$= \boxed{2569\ m/s}$$

(in 1 sig fig = 3000 m/s)

TP ✓
CP ✓
MP ✓
BP

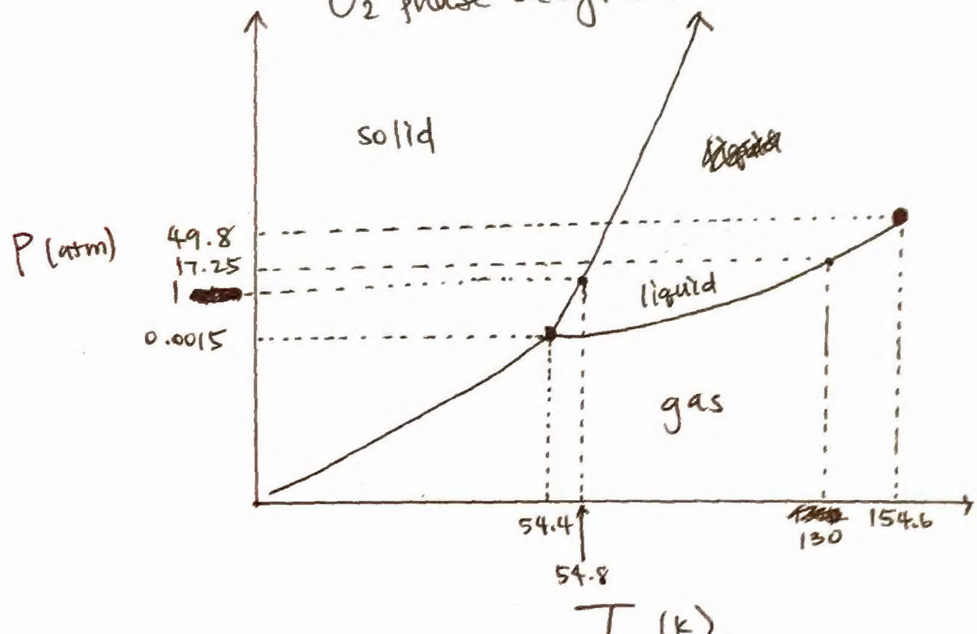
3. (15 points) For O_2 the triple point is at 54.4 K, 0.0015 atm, the critical point is at 154.6 K, 49.8 atm, the normal melting point is at 54.8 K, the vapor pressure of $O_2(l)$ at 130 K is 17.25 atm, and the densities of $O_2(l)$ and $O_2(s)$ near the triple point are 1.31 g/cm^3 and 1.36 g/cm^3, respectively. With these data construct a P vs. T phase diagram for O_2. The phase diagram need not be to scale, but you should label as many points as possible on each axis and indicate the stable phase in each P,T region.



$l = 1.31$
$s = 1.36$

TP = 54.4 K, 0.0015 atm
CP = 154.6 K, 49.8 atm
MP = 1 atm = 54.8 K (s→l)
BP = 130K = 17.25 atm

O_2 phase diagram



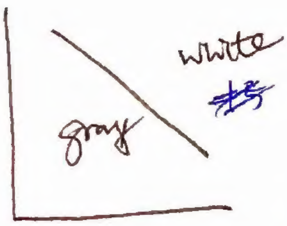
The solid-liquid boundary has a positive slope because the solid is denser than the liquid

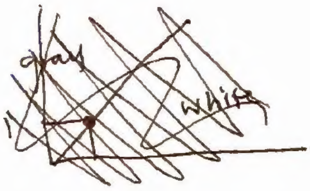
15

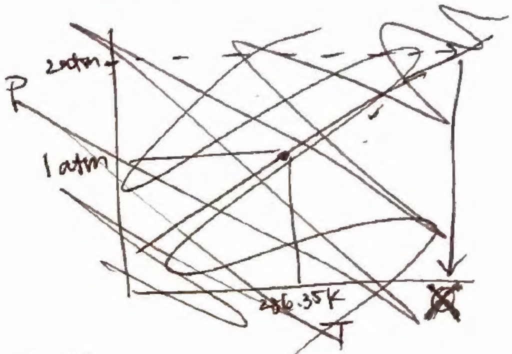
4. (15 points) Consider the phase change between white-Sn(s) and gray-Sn(s). When white-Sn(s) is cooled at 1 atm to 286.35 K it undergoes a phase change to gray-Sn(s). Given that the density of gray-Sn(s) is less than the density of white-Sn(s), would you expect the temperature of conversion from white-Sn(s) to gray-Sn(s) to be greater than or less than 286.35 K at a pressure of 2 atm? Answer by sketching out the phase boundary between the two solid phases based on the information that you have. (Hint: Just as with liquid/solid phase boundaries, higher pressure favors the phase with higher density for solid/solid phase boundaries, as well.)

(286.35, 1)

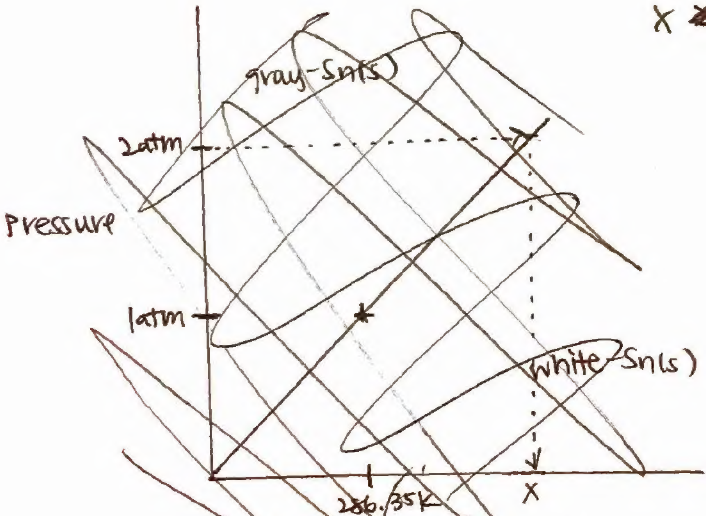
gr ← cool wh





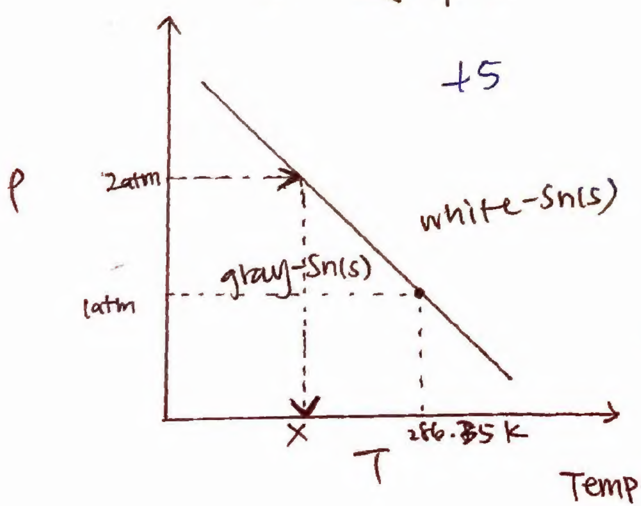


X < ~~286.35~~ K



I expect a ~~greater pressure~~ lower temperature. since the density of gray-Sn(s) is less than that of white-Sn(s), white will lie in the region above the boundary line ~~and the~~ ~~bound~~ since cooling is white to gray, white is on the right. This is reflected in the graph. The boundary line has a negative slope, so increasing pressure will decrease temp. Thus, at a higher pressure, the temperature of conversion from white-Sn(s) to gray-Sn(s) will be lower.

+5



+7

+3

Temp @ X < 286.35 K

5. (15 points) The amount of ozone ($O_3(g)$) in a mixture of gases can be determined as follows. First the gaseous mixture is bubbled through an aqueous solution of $KI(aq)$ solution, which reacts completely with the $O_3(g)$

$$\overset{0}{O_3}(g) + 3\overset{-1}{I^-}(aq) + \overset{1+\ 2-}{H_2O}(l) \rightarrow \overset{0}{O_2}(g) + \overset{-1/3}{I_3^-}(aq) + 2\overset{2-\ 1+}{OH^-}(aq)$$

to form triiodide ion I_3^-. The amount of I_3^- is then determined by titration with thiosulfate

$$\overset{-1/3}{I_3^-}(aq) + 2\overset{2+\ 2-}{S_2O_3^{2-}}(aq) \rightarrow 3\overset{-1}{I^-}(aq) + \overset{2.5+\ 2-}{S_4O_6^{2-}}(aq)$$

Suppose one starts with 50.0 L of a gas mixture containing ozone and other gases at 300 K and 1.000 bar. One then undertakes an analysis of the mixture based on the above-described procedure. The result is that it takes 30.0 mL of a 0.1187 M solution of $S_2O_3^{2-}$ to reach the end point of the I_3^- titration. Calculate the mole fraction of O_3 in the original gaseous sample.

+3

$(0.030\ L)(0.1187\ M) = 0.003561\ mol\ S_2O_3^{2-}$

+3 +3

$0.003561\ mol\ \cancel{S_2O_3^{2-}} \cdot \dfrac{1\ \cancel{mol\ I_3}}{2\ mol\ \cancel{S_2O_3^{2-}}} \cdot \dfrac{1\ mol\ O_3}{1\ \cancel{mol\ I_3^-}} = 0.0017805\ mol\ O_3$

$PV = nRT$

$(1\ \cancel{bar})(50.0\ \cancel{L}) = n\left(8.314 \times 10^{-2}\ \dfrac{\cancel{bar\ L}}{\cancel{K}\ mol}\right)(300\ \cancel{K})$

$n = 2.00465079$ mol total gas

$X_{O_3} = \dfrac{0.0017805\ mol\ O_3}{2.00465079\ mol\ total} = 8.8818\ E-4$

$= 8.88\ E-4$ +6

$\boxed{= 8.88 \times 10^{-4}}$

1 sig fig

$= 9 \times 10^{-4}$

6. (15 points) Dichromate ion can be used to oxidize Fe^{2+} in acidic aqueous solution. The unbalanced reaction is

lose e, red.

$$\overset{8+\ 2-}{Cr_2O_7^{2-}}(aq) + Fe^{2+}(aq) \rightarrow \overset{3+}{Cr^{3+}}(aq) + Fe^{3+}(aq)$$

gain e, ox

Balance this reaction equation for an acidic aqueous solution.

oxidation:

$Cr_2O_7^{2-} \rightarrow Cr^{3+}$

$Cr_2O_7^{2-} \rightarrow 2Cr^{3+}$

$Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 7H_2O$

$14H_3O^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 7H_2O + 14H_2O$

$6e^- + 14H_3O^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 21\ H_2O$

reduction:

$Fe^{2+} \rightarrow Fe^{3+}$

$Fe^{2+} \rightarrow Fe^{3+} + e^-$

combine : $6e^- + 14H_3O^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 21\ H_2O$

$+ \quad 6\times(Fe^{2+} \rightarrow Fe^{3+} + e^-)$

equalize electrons:

$\cancel{6e^-} + 14\ H_3O^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 21\ H_2O$

$6Fe^{2+} \rightarrow 6Fe^{3+} + \cancel{6e^-}$

$Cr_2O_7^{2-} + 14H_3O^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 21\ H_2O + 6\ Fe^{3+}$

~~$Cr_2O_7^{2-} + 14H_3O^+ + 6Fe^{2+} \rightarrow 2C$~~

$$\boxed{14H_3O^+_{(aq)} + Cr_2O_7^{2-}{}_{(aq)} + 6Fe^{2+}{}_{(aq)} \longrightarrow 2Cr^{3+}{}_{(aq)} + 6Fe^{3+}{}_{(aq)} + 21H_2O_{(l)}}$$

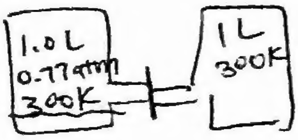
15

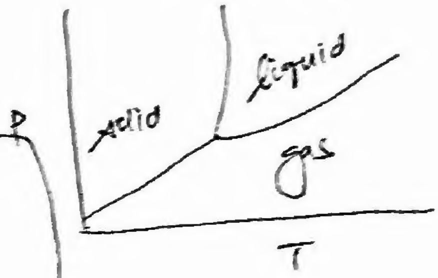
(7) Vapor pressure changes with temperature. Here, temp. is held constant therefore, vapor pressure (equilibrium) is constant.

Opening the valve increases volume and ~~and~~ suddenly decreases pressure. The system responds to this stress by increasing rate of evaporation. Thus, after opening the valve, only drops of the liquid remain.

Suddenly opening the valve increases volume and (temporarilly) decreases pressure, leading to a decrease in boiling pt temp. Thus, a larger proportion of the ~~species 2 ta~~ liquid-phase species now have enough energy to spontaneously evaporate and do so, bringing the system back to the equilibrium vapor pressure of 0.77 atm.

7. (10 points) A 1.0-L container contains a liquid in equilibrium with its vapor at 0.77 atm and 300 K. A valve connecting this container to a second, evacuated 1.0-L container is opened, allowing matter to flow freely between the two containers. The whole system then comes to equilibrium at 300 K, and one finds vapor thoughout both containers and several drops of liquid remaining in the first container. What is the pressure in the containers? Explain your answer fully.





~~PV = PV~~

~~(0.77)(1) = P(2)~~

~~P = 0.385 atm~~

Final pressure is still 0.700 atm.

see that side

that side

~~Increasing volume leads to decreasing pressure and boiling pt temperature. By opening the valve, volume is increased, pressure decreases, and the temperature @ which the liquid boils goes down. In a given sample of liquid, there is a distribution of kinetic energies. As temperature is a measure of average kinetic energy, at a certain temperature, a sample will have a proportion of its molecules have enough kinetic energy to spontaneously evaporate. Boiling point temp. can be thought of as indicating the kinetic energy a molecule must have in order for it to spontaneously evaporate. In this scenario, because pressure and therefore boiling pt temp. decreases, a larger proportion of the molecules in the species now possess enough kinetic energy to spontaneously evaporate, leaving only drops behind.~~

(see back side!)